SIRTF in High Earth Orbit

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1 Introduction

The exciting scientific results reported from the first use of large format infrared arrays at ground-based telescopes (Gatley *et al.* 1988) set the stage for the eventual application of this technology on cryogenic telescopes in space. The difference in infrared sky brightness seen by a cryogenic space telescope, versus an ambient temperature ground-based or airborne facility, is comparable to the difference in visible sky brightness at night versus day. This reduction in background brightness places an enormous gain in sensitivity within our grasp. Space telescopes also have a clear view of all infrared wavelengths, unimpeded by atmospheric absorption. The first cryogenic space telescope to take full advantage of the new generation of infrared detector arrays will be the Space Infrared Telescope Facility (SIRTF–Figure 1). Indeed, much of the work reported at this conference on detector arrays for space applications at wavelengths longward of 2.5μm was stimulated and/or supported by the SIRTF detector technology program.

SIRTF will be an observatory class facility for infrared astronomy, carrying three instruments providing a broad range of capabilities. With the Hubble Space Telescope, the Advanced X-Ray Astrophysics Facility, and the Gamma Ray Observatory, SIRTF makes up NASA's family of Great Observatories. Most of the observing time over the SIRTF mission lifetime (currently estimated as 5 years with a substantial safety margin) will be used by general observers drawn from the broad astronomical community.

SIRTF has been under study and development by NASA for over a decade. The SIRTF Science Working Group (Table 1) and instrument teams were selected in 1984. Efforts since then have focussed on validating the system performance requirements, working on key telescope and instrument technology areas, and optimizing all portions of the mission. SIRTF stands second in the queue for major missions within NASA's Office of Space Science and Applications. The current schedule for SIRTF calls for initiation of the final design and fabrication activities (Phase C/D) in 1992/3, leading to launch in 1998.

In the spring of 1989, NASA adopted a new approach to SIRTF, utilizing an expendable vehicle launch into a high earth orbit (HEO – orbital altitude 100,000 km above the Earth's surface). The main purpose of this article is to introduce the HEO mission and the advantages which it will bring over the previous 900 km altitude low earth orbit (LEO) approach. In addition, we emphasize the importance for SIRTF of the continuing developments in infrared array technology. More complete discussions of SIRTF's scientific objectives and potential can be found in Rieke *et al.* (1986) and in a series of articles in Astrophysical Letters and Communications (Vol. **27** No. 2, pp. 97 ff., 1987). The (LEO) SIRTF mission and SIRTF instruments are more fully described in Werner *et al.* (1986) and Ramos *et al.* (1988).

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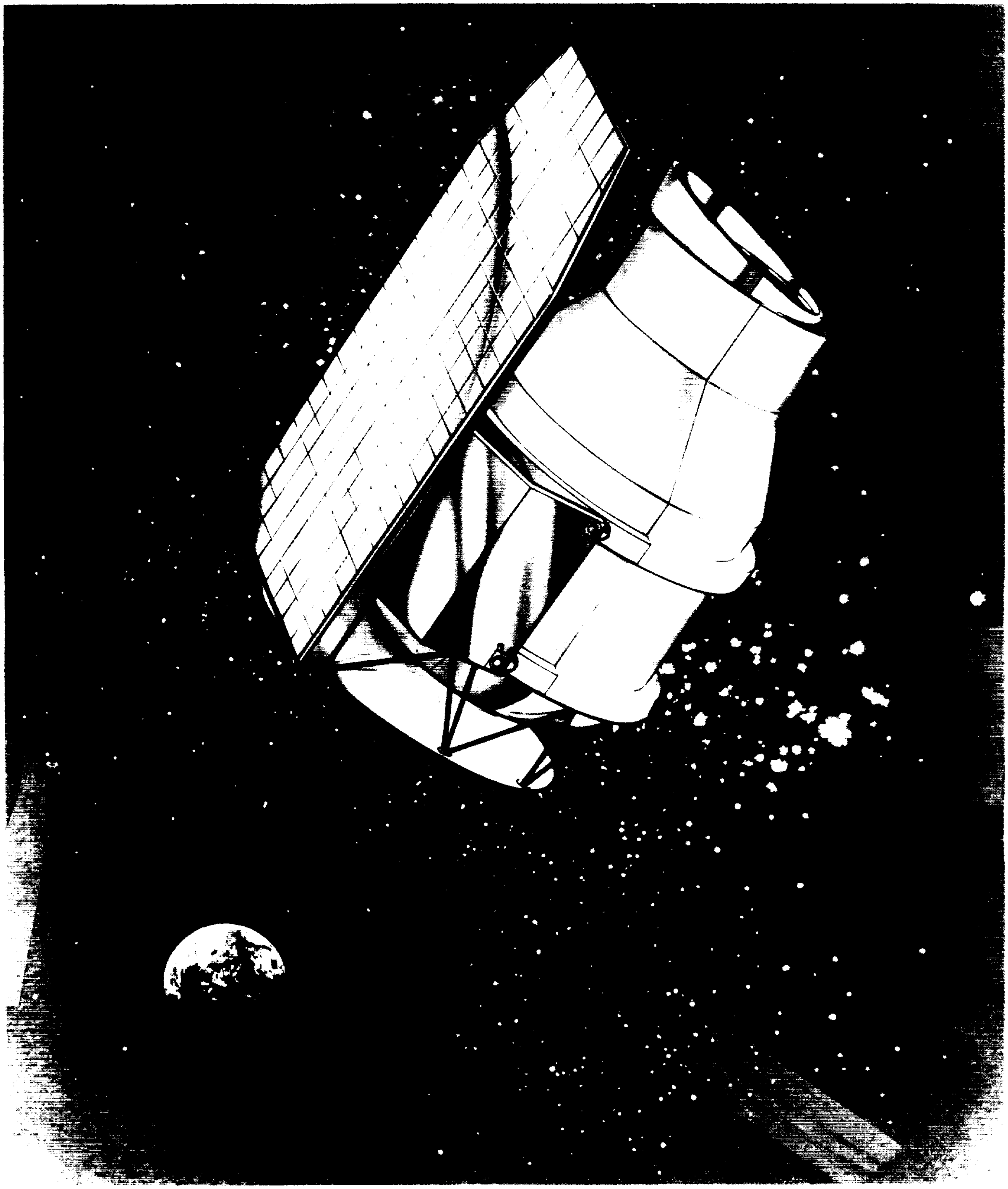

Figure 1: The Space Infrared Telescope Facility (SIRTF), shown in its new high altitude Earth orbit (HEO) configuration.

Table 1: SIRTF Science Working Group.

Giovanni G. Fazio, Smithsonian Astrophysical Observatory	Principal Investigator (PI), Infrared Array Camera (IRAC)
James R. Houck, Cornell University	PI, Infrared Spectrograph (IRS)
George Rieke, University of Arizona	PI, Multiband Imaging Photometer for SIRTF (MIPS)
Michael Jura, UCLA	Interdisciplinary Scientist
Frank Low, University of Arizona	Facility Scientist
Edward L. Wright, UCLA	Interdisciplinary Scientist
Dale Cruikshank, NASA/Ames	Interdisciplinary Scientist
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2 Rationale and Requirements

The fundamental rationale for a cryogenic telescope in space is shown in Figure 2, which compares the infrared background brightness of the earth's natural astrophysical environment with that encountered by an ambient temperature telscope operating within the atmosphere. The natural astrophysical background radiation includes contributions from the zodiacal dust cloud, diffuse galactic dust, and the 3 K cosmic background. These natural backgrounds are more than a million times lower than those characteristic of Earthbound ambient temperature telescopes. The minima in the natural backgrounds around 3 and 300μm are particularly noteworthy, as sensitive observations in these windows may provide unique views of the distant, early universe. Because the limiting sensitivity improves with the square root of the background brightness, even a modest sized cryogenic space telescope, such as SIRTF, can have a thousand or more times the sensitivity of a large ground based telescope. SIRTF's goal is therefore to reduce both the thermal emission of the telescope and scattered and off-axis radiation sufficiently so that its performance can be "natural-background limited" at wavelengths between 2 and $\gtrsim$ 200μm.

SIRTF's scientific objectives require not only high sensitivity but also excellent performance in many other areas. The resulting system parameters and requirements are listed in Table 2. Also shown for comparison are the parameters for the Infrared Astronomical Satellite (IRAS), the pioneering cryogenic infrared space telescope (Neugebauer *et al.* 1984). IRAS, which flew in 1983 and carried out the first sensitive all-sky survey at infrared wavelengths, established the scientific and technical framework for the development of SIRTF. Although the size difference between the telescopes is not large, SIRTF goes far beyond IRAS in many important scientific dimensions: wavelength coverage, spatial and spectral resolution, sensitivity, and lifetime. The European Space Agency's Infrared Space Observatory (ISO – Kessler 1986), scheduled for launch in 1993, will have capabilities intermediate between those of IRAS and SIRTF. SIRTF's biggest gains result from the fact that its instruments will be equipped with large arrays having up to tens of thousands of detector elements, as is discussed further in section 4. Thus SIRTF will be an extremely powerful observatory, capable not only of following up the discoveries made by IRAS and by ISO, but also of extending our knowledge of the infrared universe still further back in both space and time.

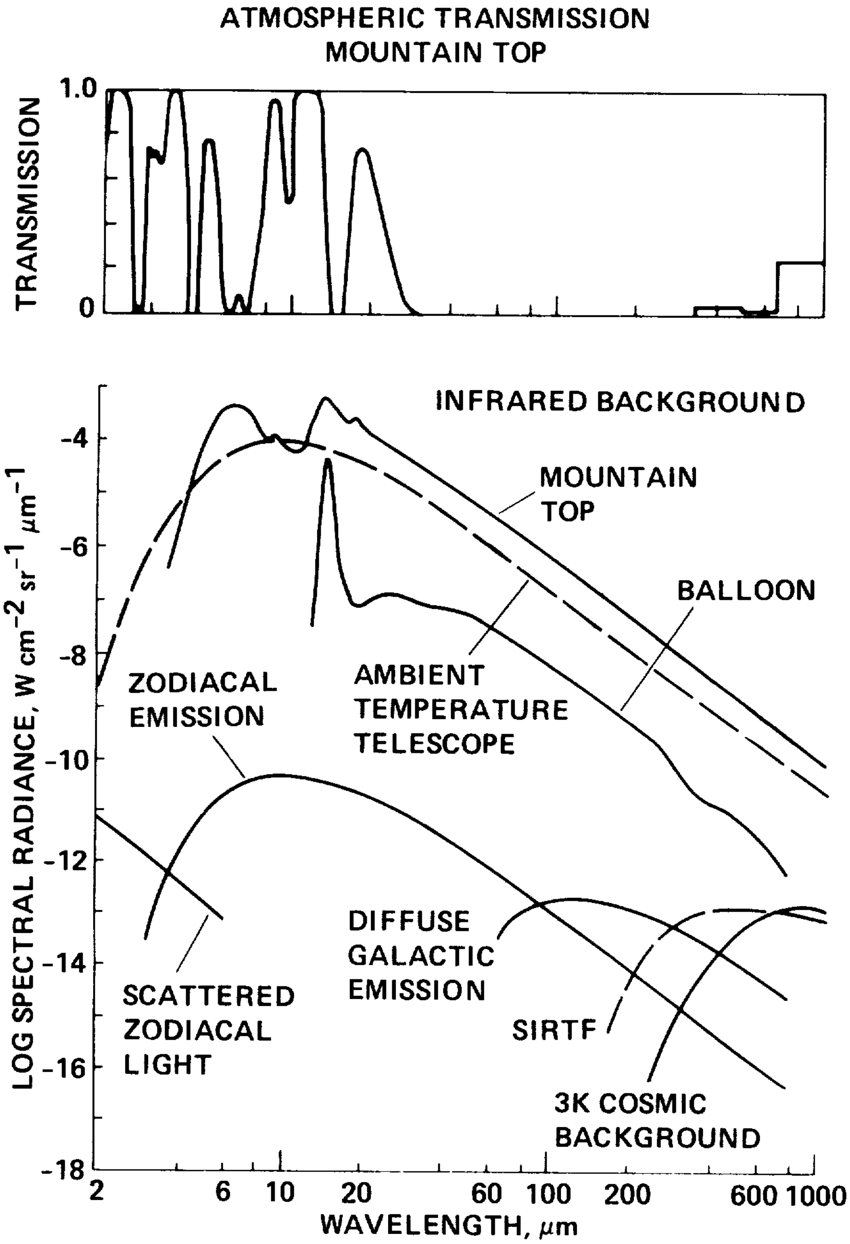

Figure 2: Atmospheric transmission and background fluxes for infrared astronomy. The upper panel shows the atmospheric transmission seen from a good mountain top observatory, illustrating that much of the infrared spectrum is completely inaccessible from the ground. Solid curves in the lower panel show the infrared background flux in three observing environments: a good mountain top observatory, high balloon altitudes, and space. Atmospheric background flux at airplane altitudes is intermediate between the curves for the mountain observatory and the balloon. The natural astrophysical background radiation in space is the sum of scattering and emission by zodiacal dust grains, emission by diffuse galactic dust, and the 3 K cosmic background radiation. Dashed curves show the background contributions from optimized infrared telescopes: an ambient temperature instrument (such as would be used from the ground, airplanes, or balloons) and SIRTF. The total background at the infrared detector is the sum of the natural and telescopic contributions.

Table 2: Comparison of SIRTF and IRAS System Parameters

Parameter	SIRTF	IRAS
Mirror Diameter	95 cm	60 cm
Wavelength Coverage	1.8 – 700μm	8 – 120μm
Diffraction-Limited Wavelength	2.5μm	$\sim$ 15μm
Angular Resolution at Wavelength λ	$\lambda/4\mu$m arcsec	$\gtrsim$ 15 arcsec
Pointing Stability/Accuracy	0.15/0.15 arcsec	2 arcsec
Sensitivity:[1]		
10 μm	6 μJy	70 mJy
60 μm	150 μJy	70 mJy
Number of Detectors	$\gtrsim$ 10,000	62
Spectral Resolving Power	$\gtrsim$ 2000	20
Mode	Observatory	Survey
Lifetime	> 5 years	10 months

[1]One sigma in 500 seconds of integration for SIRTF, and in one survey pass for IRAS.

3 Mission Options Study

NASA's decision following the Challenger accident to employ a mixed fleet of launch vehicles encouraged the SIRTF team to explore alternate mission approaches to achieving SIRTF's science objectives. In an initial study phase concluded in mid-1988, a circular orbit at an altitude of approximately 100,000 km above the Earth was selected for detailed study and comparison with the 900 km altitude baseline mission (Figure 3). These two altitudes are, respectively, just above and just below the Earth's Van Allen belts, whose trapped energetic particles would degrade infrared detector performance. The rules of the comparison stipulated that both missions satisfy the requirements in Table II and that both be capable of supporting the complement of three instruments selected for SIRTF.

The HEO mission concept outlined below is the result of six months of intensive study headed by the Ames Research Center with support from the SIRTF Science Working Group, the Jet Propulsion Laboratory, the Marshall Space Flight Center, and the Lewis Research Center. An alternative HEO option, in which SIRTF is flown at the Earth-Sun L2 Lagrangian point (1.5 million km in the anti-solar direction), was proposed by the Goddard Space Flight Center. Further optimization of the HEO concept will take place during the SIRTF Phase B studies beginning in 1990.

3.1 The HEO Mission

The new mission will use a Titan IV/Centaur to launch a 5 m long, approximately 4,500 kg SIRTF into a 100,000 km altitude, 28.5° inclination orbit with a period of $\approx$ 100 hours. Seen from this altitude, the Earth subtends an angle of less than 7° (vs. 122° in LEO), so it is possible to maintain a flexible viewing strategy while constraining the telescope to point no closer than 80° to the Earth or Sun limb. This orbit allows the use of a fixed solar panel, which shades the telescope and lowers the predicted temperature of the telescope outer shell to 110K. Eclipses are infrequent in this orbit; the time and date of launch can be selected to orient the orbit so that the spacecraft passes through the Earth's shadow only a few days each year. Reaction wheels provide slewing and fine pointing capability. Environmental disturbance torques are small, but momentum control requires the use of cold gas because the Earth's magnetic field is too weak for momentum dumping at 100,000 km. The helium boil off from the cryogen system and a small tank of compressed helium gas will be used for this purpose. Science and engineering data will be stored on-board the spacecraft and downlinked

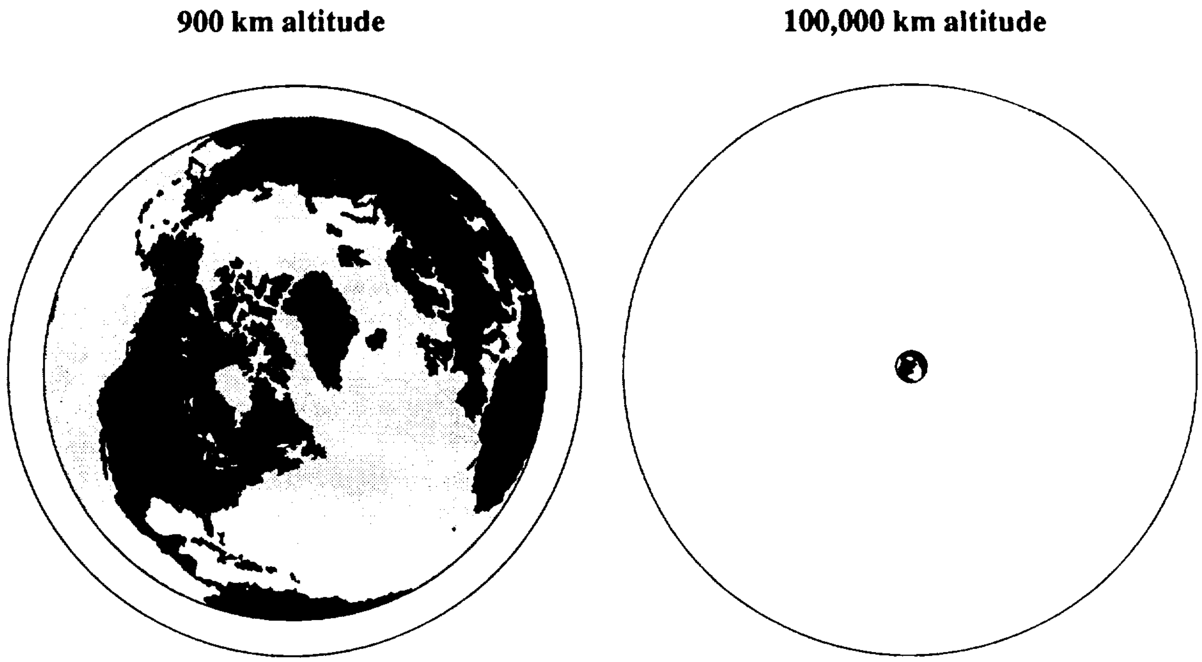

Figure 3: Relative size of the Earth in comparison to the low Earth orbit (LEO – on left) and high Earth orbit (HEO – on right).

8 hours per day via a fixed omnidirectional antenna to the 26 m dishes of the Deep Space Network.

Figure 4 shows a cutaway view of the telescope concept for the HEO mission. The IRAS heritage is shown in the annular cryogen tank, containing 4000 liters of superfluid helium which cools the optics and baffles, and in the truncated "sugar scoop" aperture shade, which allows the telescope to point as close as 80° to the Earth and Sun limb. The optical system is an f/24 Ritchey-Chrêtien design with a 95 cm f/2.3 primary mirror. The secondary mirror will be used for conventional chopping at the longer wavelengths and for flat-fielding and scanning procedures at the shorter wavelengths. Within the multiple instrument chamber, a rotatable dichroic tertiary mirror will direct the entire seven arcminute field of view to whichever instrument is in use, while the optical image is passed to a fine guidance sensor which will be used with the spacecraft gyros to provide pointing and stabilisation.

3.2 Technical Concerns

The two principal technical concerns which arose during the study of the HEO SIRTF option were in the areas of launch vehicle capability and lifetime. The present HEO baseline configuration has a mass of 4370 kg. By comparison, the expected Titan-Centaur launch capability to 100,000 km for a SIRTF-sized payload is at least 5770 kg. It is felt that the 1400 kg difference (36% of the current mass excluding the helium) is adequate margin in this critical area.

The cryogen lifetime is an issue in HEO because on-orbit cryogen refill, which was to be used in LEO to achieve the five year lifetime, will not be available in this option. Preliminary optimisation of the 4000 liter HEO system yields an estimated useful on-orbit cryogen lifetime (exclusive of losses due to launch holds, on-orbit cooldown, etc.) of six years, giving a 20% margin over the requirement. The dramatic increase over the 2.5 year lifetime predicted for the same size dewar and the same instrument complement in LEO reflects:

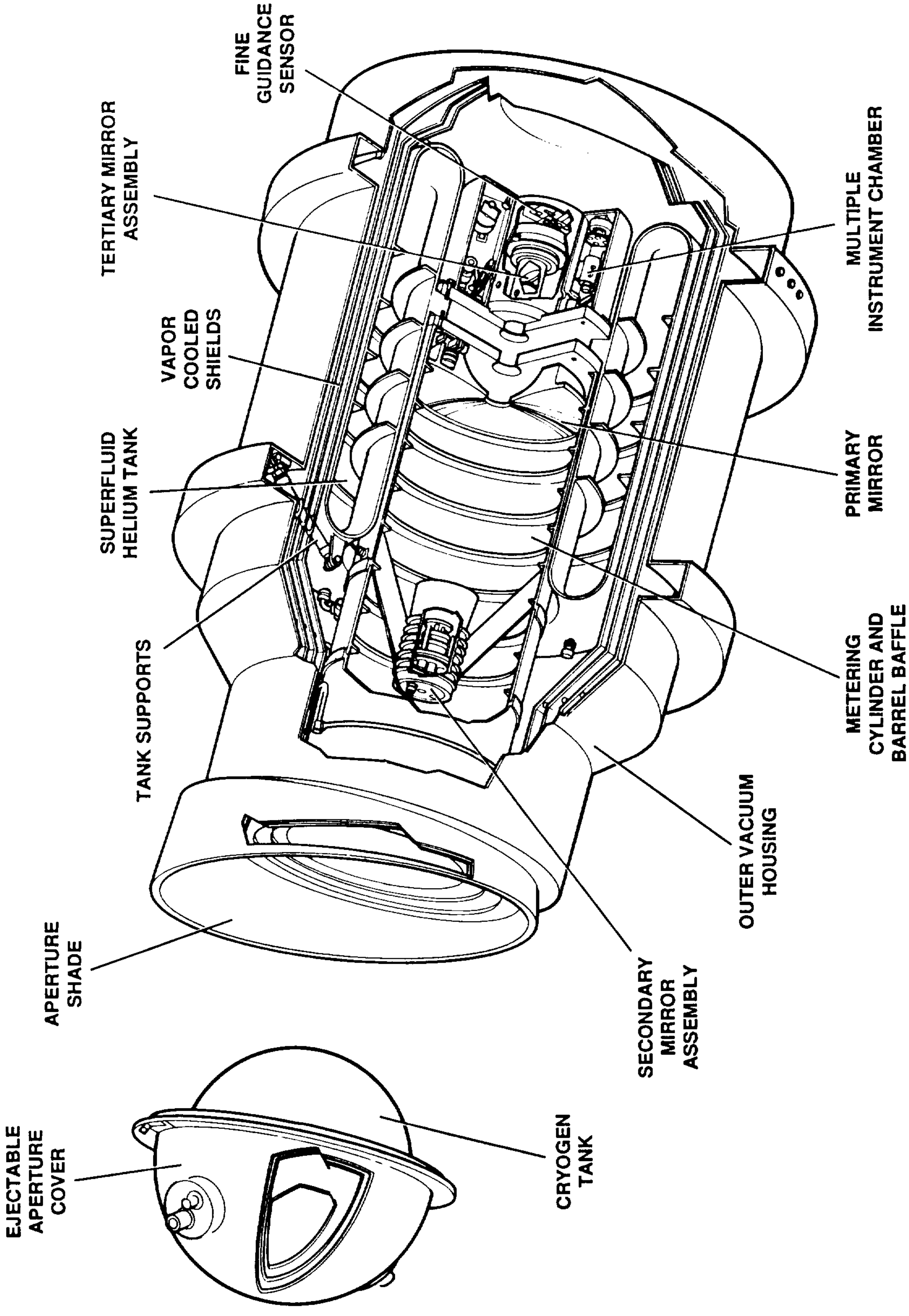

Figure 4: Cutaway view of the SIRTF telescope concept for the HEO mission.

1. the lower outer shell temperature (110K vs. 220K) achievable in HEO due to the greatly reduced heat load from the Earth and to a lesser extent to the shading provided by the fixed solar panel; and
2. reduction by more than an order of magnitude in the "aperture load" - the power radiated into the dewar by the aperture shade - which results from the fact that the aperture shade in HEO is both smaller and colder than in LEO.

3.3 Comparison of HEO and LEO Missions

3.3.1 Overall Configuration

Figure 3 shows the relative sizes of the Earth and SIRTF'S orbit for the HEO and LEO missions, while Figure 5 compares the general configuration of the orbiting observatories in the two missions, with IRAS shown for reference. Both missions have an orbital inclination of 28.5° to maximize the launch capability and to permit servicing in the LEO mission. The 280-fold reduction in solid angle subtended by the Earth in HEO leads to the thermal advantages cited above and also permits more freedom in telescope pointing, even though the solar and terrestrial avoidance angles are larger in HEO. These larger avoidance angles cannot be satisfied when SIRTF passes directly between the Earth and Sun in the LEO mission. The 122° angle subtended by the Earth permits Sun and Earth avoidance angles no greater than 59° at these times, which occur for several orbits approximately every 28 days. The use of the larger avoidance angles (80°) in HEO leads to a smaller aperture shade, which in turn permits the forward portion of the telescope baffle tube to be shortened while maintaing the required rejection of stray radiation. The reduction in aperture shade size and forebaffle length lead to the overall shortening of the system shown in Figure 5. Note also in Figure 5 that the solar arrays and antennas are fixed in the HEO system but must be deployable and steerable in LEO. The dewar, optical system, and instruments are essentially identical in the two concepts. Thus the analysis and technology work done on these system elements for LEO carries over directly into the HEO system.

3.3.2 Operations

On-orbit science operations in HEO will benefit from the reduced Earth solid angle, the long orbital period (100 hours vs. 100 minutes in LEO), and the absence of the South Atlantic Anomaly (SAA - see section 3.3.3 below). In addition, the contamination constraint introduced in LEO that the telescope not point into the "wind" created by the orbital motion of the spacecraft does not apply in HEO, where the atmospheric density is negligible. Depending on the relative location of the Sun, Earth and spacecraft, SIRTF can view instantaneously 14 to 33% of the sky in HEO but only < 1 to 12% in LEO. In HEO, there are zones over the orbit poles (≈ 200 square degrees in total) which can be viewed continuously, and accessible targets elsewhere in the sky can typically be observed for 50 or more consecutive hours. By contrast, there is no direction which can be viewed continuously in LEO, because the combination of Earth limb and "wind" avoidance constraints limit the maximum viewing time per target to 15 minutes. These and similar considerations suggest that the observation planning and scheduling process will be much more straightforward in HEO. Maintaining the Earth avoidance constraint in LEO means that tens of minutes in each 100 minute orbit must be spent in large angle slews. Observing efficiency simulations for LEO including sky visibility, slewing, and time lost to the high proton fluxes in the SAA, indicate that the average efficiency (fraction of time on-target) would be about 45%. The corresponding efficiency in HEO is estimated at 90%.

3.3.3 Ionizing Radiation Environment

In LEO, the main radiation effects are due to the intense fluxes of trapped and highly energetic protons encountered during passages through the SAA, a low lying region of the Van Allen belts. These

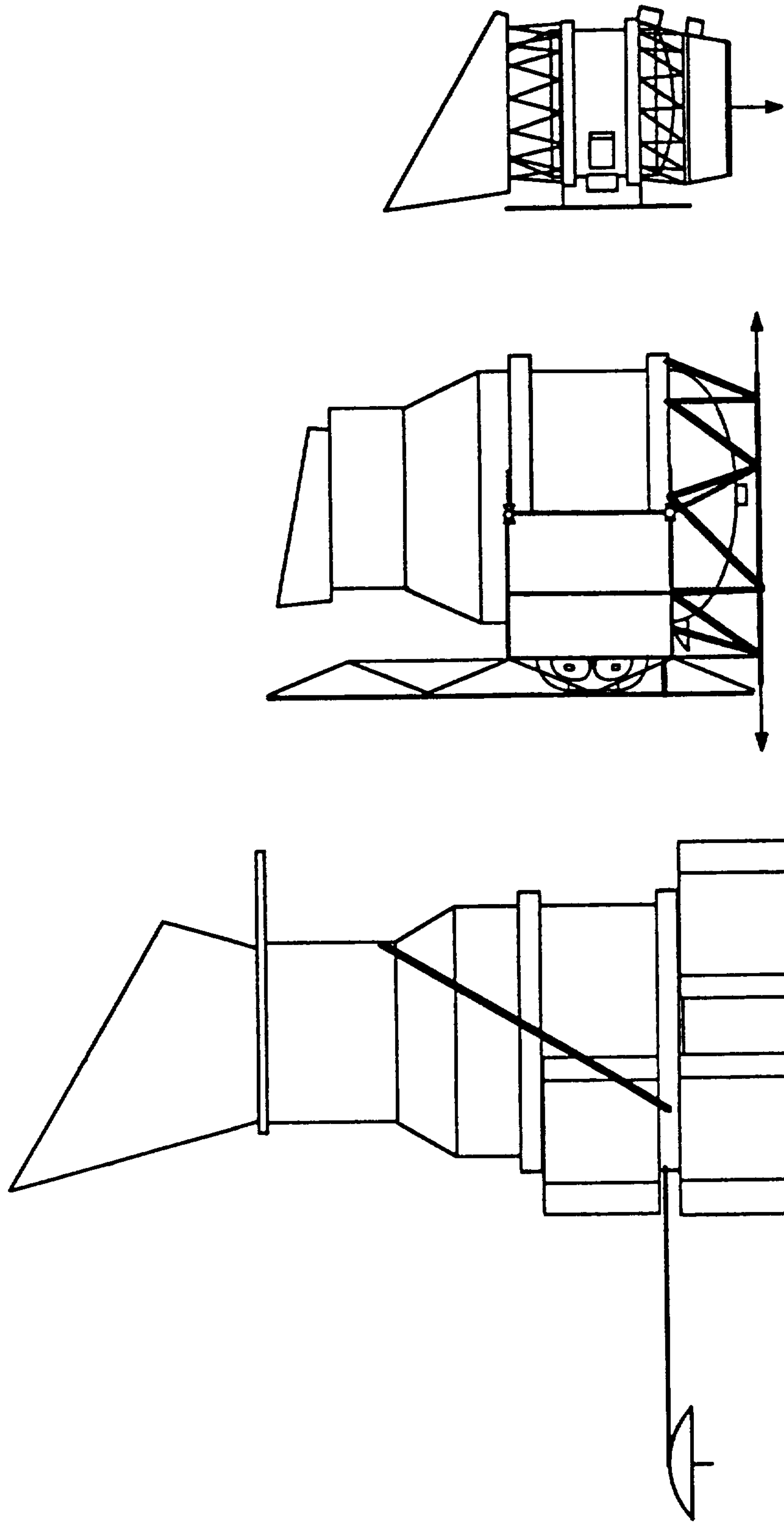

Figure 5: General configuration of the LEO (bottom) and HEO (center) SIRTF concepts, and of IRAS (top). The masses and lengths of the three satellites are 6620 kg, 4370 kg, 1080 kg; and 8 m, 5 m, and 3.7 m respectively.

passages occur almost every orbit and render about 25% of the time unsuitable for observations. Because these high fluxes alter detector response, additional time would be required for post-SAA annealing and recovery. In HEO, analysis of satellite data shows that only a few percent of the time is likely to be lost to quasi-trapped electrons and to solar flares. However, without the shielding effect of the Earth's magnetic field, the *quiescent* (cosmic ray) hit rate is predicted to be a few times higher than that expected for LEO outside of the SAA, leading to a reduction in sensitivity for certain instrument modes. Thus radiation effects would be a concern in either orbit, and radiation testing continues to be an important part of the SIRTF detector technology program.

3.3.4 Risk and Complexity

The HEO mission appears to have lower operational risk than the LEO option. In LEO the performance and system lifetime depend critically on maintaining the cleanliness of the telescope and the aperture shade, which are subject to contamination both by the residual atmosphere and by problems which could occur during a servicing mission. In addition, an emergency safe-hold mode is simply achieved in HEO by pointing at the constant viewing zone, while in LEO a complex series of pointing constraints must be continually satisfied. Finally, the use of fixed solar arrays and antennas in HEO eliminates the risk of failure during deployment or operation of these mechanisms.

3.3.5 Scientific Performance

The features of the HEO mission summarized above improve the scientific performance of SIRTF in many ways, including the following areas of particular importance:

- The doubled on-target efficiency means that the HEO mission will support twice the number of investigations, and produce twice the quantity of data, as the LEO mission.

- The longer on-target times and greater sky accessibility in HEO will allow SIRTF to operate in a true observatory mode, in which a single scientific investigation can be scheduled in an unbroken block of time. Data from the completed observation will be available to the observer more quickly, and will be more uniform and easier to calibrate and reduce, than if it were obtained on many successive orbits in the LEO mission.

- The long wavelength $> 100\mu$m performance will be improved in HEO. SIRTF's sensitivity at these long wavelengths will be influenced by radiation from the telescope itself. To reach natural-background limited performance at 300μm requires a forebaffle temperature of 7K or below; the predicted temperature is 4K in HEO and 8 to 14K in LEO. The longer on-target times and much less frequent eclipses in HEO imply that the temperature will be more stable as well as lower. These effects together should allow the HEO mission to achieve far better performance in the cosmic window at 300μm, where recent results (Matsumoto *et al.* 1988) indicate that many important cosmological questions can be investigated.

- Performance at the 3μm window may also be improved in HEO. The extremely low background photon rate means that observations (especially spectroscopy) near this wavelength are likely to be limited by detector read noise (see section 4) in 15 minutes, the maximum integration time in LEO. Under these circumstances, n^2 15 minute integrations must be combined in LEO to equal the sensitivity of a single $(n \times 15)$ minute integration in HEO. However, the benefits of longer continuous integration times in HEO may be offset by the higher cosmic ray rates.

- The high galactic latitude sky (latitude greater than 60°) can be observed at any time during the HEO mission, but is accessible only about 25% of the time in LEO. This is important because many of SIRTF's most important scientific objectives, including deep cosmological surveys, will require extended access to high latitudes.

Table 3: SIRTF Instrumentation Summary

Instrument	Principal Investigator	Characteristics
Infrared Array Camera (IRAC)	G. Fazio, Smithsonian Astrophysical Observatory	Wide field and diffraction limited imaging, $1.8 - 30\mu m$, using arrays with up to 256×256 pixels. Simultaneous viewing in three wavelength bands, selectable filters. Polarimetric capability.
Infrared Spectrometer (IRS)	J. Houck, Cornell University	Grating spectrometers, $2.5-200\mu m$, using two dimensional detector arrays. Resolving power from 100 to 2500. Low and high resolution options at most wavelengths.
Multiband Imaging Photometer for SIRTF (MIPS)	G. Rieke, University of Arizona	Background limited imaging and photometry, $3 - 200\mu m$, using small arrays with pixels sized for complete sampling of Airy disk. Wide field, high resolution imaging, $50 - 120\mu m$. Broadband photometry and mapping, $200 - 700\mu m$. Polarimetric capability.

3.4 Summary

The consensus of the SIRTF Study Office at Ames, the other NASA centers which participated in the Mission Options Study, and the SIRTF Science Working Group is that the high orbit offers significant scientific and engineering advantages for SIRTF. These advantages have been summarized above. As a result, the HEO mission has been adopted by NASA as the new baseline. This selection of an orbit optimized to maximize the scientific productivity of the mission, together with the dramatic advances in detector performance which are the subject of these proceedings, has brought the promise of SIRTF close to realization.

4 Instruments and Arrays

The properties of the three instruments under development for SIRTF are briefly summarized in Table 3. The Multiband Imaging Photometer and the Infrared Array Camera, using arrays with up to 256×256 pixels, will provide wide field and high resolution photometry, imaging, and surveying capabilities. Scientific objectives include imaging of objects ranging from comets to galaxies, mapping of extended regions of star formation, and deep surveys at SIRTF's limiting sensitivity. The Infrared Spectrograph will have low and moderate spectral resolution modes, using arrays to provide spectral imaging with > 10 spatial elements along the slit and > 50 spectral elements in the dispersion direction. Scientific objectives include studies of composition and physical conditions in planetary atmospheres, the interstellar medium, and external galaxies. The spectrograph will also be used to determine the nature of objects discovered in SIRTF's surveys, many of which will be too faint to be studied in detail from other platforms.

While SIRTF's larger size and superior imaging capabilities provide substantial improvements over IRAS and ISO, SIRTF's most dramatic gains will result from improved detector - and hence instrument - performance. Much of the SIRTF resources over the past several years have been devoted to detector and array development and characterization. This program has been carried out in a coordinated way among the instrument teams (Houck 1987), and the success of the activity

NATURAL BACKGROUND FLUX

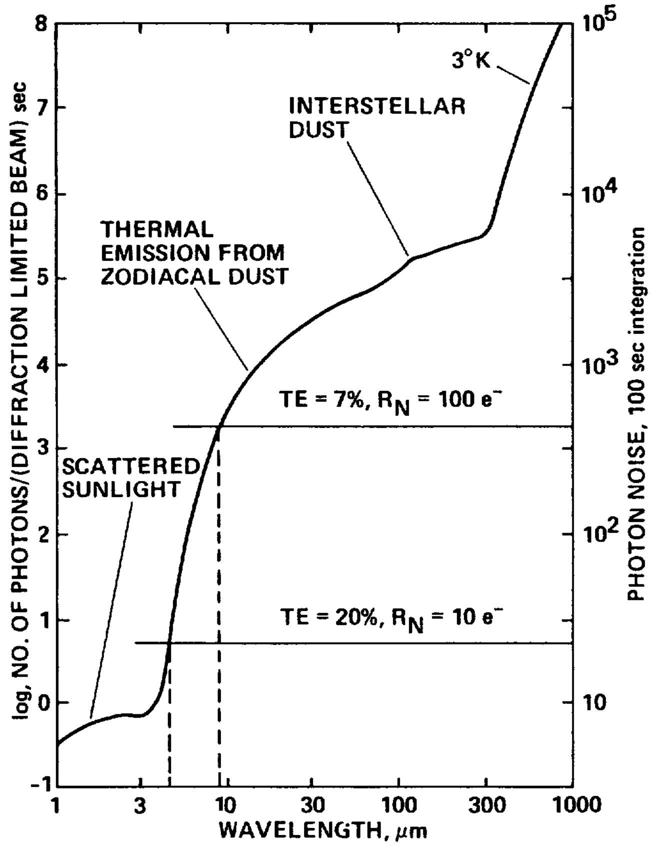

Figure 6: Natural infrared background vs. wavelength. The left vertical axis shows the photon arrival rate for spectral resolution $\lambda/\Delta\lambda = 100$ and pixel solid angle $\Omega = (2.4\lambda/D)^2$, typical for the SIRTF spectrograph, or equivalently for $\lambda/\Delta\lambda = 4.3$ and $\Omega = (\lambda/2D)^2$, typical for SIRTF photometry. The right hand axis gives the corresponding photon noise in 100 seconds of integration. The primary background contributor for each wavelength regime is indicated. Horizontal lines show the effective read noise (R_N) of instruments with stated values of transmission times quantum efficiency (TE). Background and read noise curves intersect at the wavelength where the two noise sources are equal.

is apparent from the many reports on the SIRTF detector work included in this volume. Except at wavelengths beyond 200μm where bolometers will be employed, SIRTF will use arrays of charge integrating detectors, characterized by a read noise, which is determined by the detector itself and by the readout or multiplexing circuit to which it is mated. Figure 6, adapted from Houck (1987), shows the background photon rate for combinations of bandwidth and field of view which represent typical observing conditions for the low spectral resolution spectrograph and high spatial resolution photometer modes. To achieve background limited performance in integration time t requires, approximately, that the read noise be less than the square root of the number of background photons detected during that time. For example, for the parameters relevant to Figure 6 and a 100 second integration, a read noise of 100 electrons will allow background limited operation at all wavelengths longer than 10 μm, as shown by the upper horizontal line.

Table 4 summarizes the materials and current performance of the arrays now under test for the various bands of the SIRTF instruments. The pixel formats shown are those anticipated to be used in flight. The test results are for detectors with non-optimized sizes and formats ranging from single elements to 58 $\times$ 62 arrays. The details of these developments are given elsewhere in this

Table 4: SIRTF Array Performance Status

Material	Format	Pixel Size (μm)	λ (μm)	Q.E.	R_N (e^-)	I_D (e^-/sec)	Respon-sivity(A/W)
HgCdTe	256×256	40	$1-5$	0.3	90	50	0.8
InSb	256×256	40	$1.8-5.3$	0.5	168	< 2.4	2.0
Si:Ga	128×128	100	$4-18$	0.3	50	90	14
Si:As BIBIB	128×128	100	$4-28$	$0.2-0.5$	77	8	68
Si:Sb	128×128	100	$14-30$	0.3	50	13	3.8
Ge:Be	2×25	500	$30-52$	$0.3-0.4$	75	< 100	12
Ge:Ga	32×32	500	$50-120$	0.2	25	500	39
Ge:Ga BIB	1×20	500	$50-190$	0.04		10^6-10^7	5
Ge:Ga (Stressed)	1×20	500	$120-200$	0.1	75	1000	100

volume. Meeting SIRTF's goals of achieving diffraction limited imaging with sensitivity limited by the natural astrophysical background is particularly challenging at the shortest wavelengths. Large detector arrays are required to fully sample the field of view, and the extremely low background level at the 3μm cosmic "window" demands detectors with correspondingly low read noise and dark current which are capable of long integration times. Basic characterization of detectors for this band is still underway. But the goal of background limited performance is in hand across most of SIRTF's spectral band. The emphasis in the detector development program is shifting to include more specialized issues such as linearity, hysteresis, and susceptibility to charged particles.

The scientific impact of the use of arrays on SIRTF can be illustrated by the following example. An important scientific objective for SIRTF will be to search in various astrophysical environments for "brown dwarf" stars - stars with mass $< 0.08 M_\odot$ which are unable to sustain nuclear burning processes but which may be visible in the infrared through the faint glow of their escaping internal heat. One region to search for brown dwarfs is in a star cluster such as the Pleiades, which contains numerous recently formed low mass stars. Based on the currently projected performance of the baseline 58 x 62 pixel arrays in the 5-15μm region, SIRTF in 3 days can map the entire central square degree of the Pleiades to sufficient depth to identify all brown dwarfs with masses greater than $0.01 M_\odot$. Extrapolation based on the recent results of Stauffer *et al.* suggests that these maps would reveal $>$ 50 such objects. Thus three days of observation would produce definite results illuminating such fundamental questions as: the nature of the "missing mass" in the galactic disk; the formation of low mass stars and the shape of the faint end of the main sequence; and the behavior of helium-hydrogen mixtures at high densities. Even at SIRTF's background-limited sensitivity, this important investigation would take a prohibitively long time without the large number of detectors provided by the large array.

5 Summary and Conclusions

Figure 7 shows the expected performance of SIRTF, compared to that of other facilities for infrared astronomy and to the predicted fluxes of selected astronomical targets. One sigma sensitivity limits are shown for broadband observations with the currently available large groundbased and airborne telescopes and for the IRAS survey. For SIRTF, one sigma sensitivity for a point source is shown for broadband imaging and for moderate resolution (R = 1000) spectroscopy. This figure does not properly reflect the additional quantitative and qualitative gains which will result from the use of large detector arrays on SIRTF, as illustrated in the previous paragraph. Further gains will come from SIRTF's long lifetime, total freedom from atmospheric absorption, high photometric and

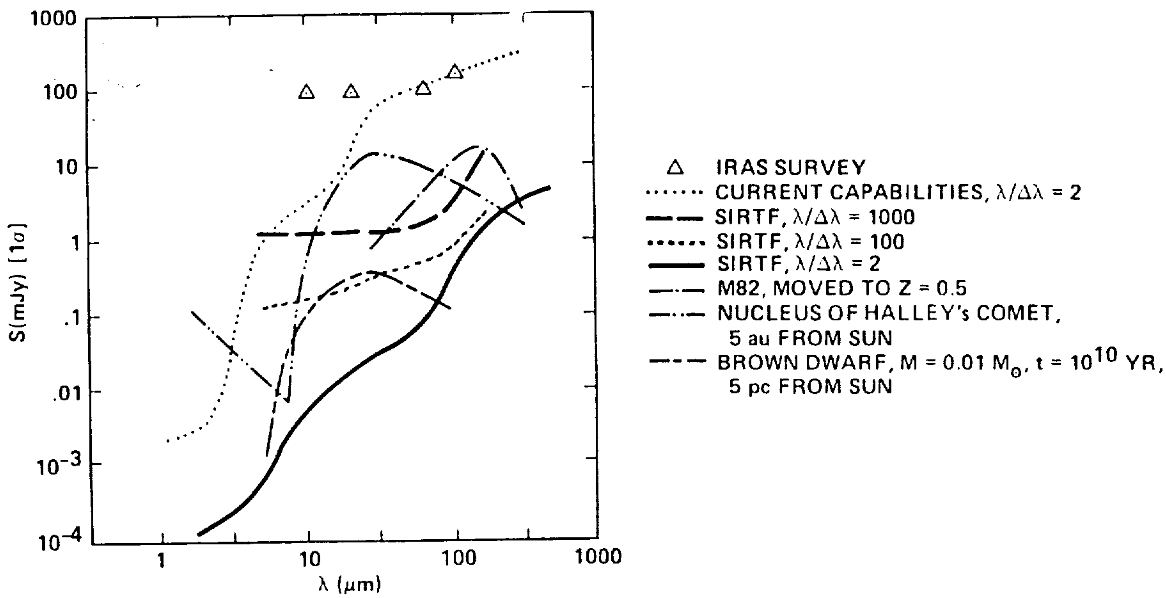

Figure 7: Comparison of background-limited sensitivity limits for SIRTF in imaging and spectroscopic modes (500 sec. integration), IRAS (survey mode), and current groundbased and airborne telescopes (1 hr.). Also shown are expected fluxes for the nucleus of Halley's comet, M82 at a redshift of 0.5, and a 0.01 $M_{\odot}$ brown dwarf at 5 pc.

radiometric stability, broad and simultaneous wavelength coverage, and speed of data acquisition. Together, these factors will make SIRTF an extremely powerful instrument for the study of a very broad range of solar system, galactic, and extragalactic problems.

Figure 7 illustrates that the faintest IRAS sources cannot even be detected with existing instruments, but that SIRTF will be able to take spectra of them easily. SIRTF will allow the first detailed study of the infrared properties of objects as diverse as cometary nuclei and distant galaxies. Predicted but unseen phenomena such as brown dwarfs will come within the range of SIRTF's capabilities. But the most exciting objects SIRTF will study are not shown in Figure 7, because they will be the unexpected discoveries that inevitably follow such major gains in sensitivity.

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